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Blazeguard: A Precision-Driven Hexacopter Drone for Urban Firefighting

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Abstract

Urban areas face unique challenges in firefighting due to population density, narrow streets, and limited accessibility. Conventional firefighting methods often struggle to address these challenges effectively. This paper introduces Blazeguard, an advanced hexacopter drone equipped with precision fire-extinguishing capabilities and autonomous navigation. Blazeguard utilizes a combination of state-of-the-art sensors, GPS-based navigation, and a custom-built claw mechanism to deploy fire-extinguishing ball accurately. Through a series of controlled experiments, Blazeguard demonstrated its ability to enhance firefighting operations by rapidly reaching inaccessible fire locations and providing real-time situational awareness. This study discusses the drone's design, implementation, results, and future prospects, including the integration of heat-resistant materials and swarm robotics for coordinated large-scale firefighting

Keywords: firefighting technology, hexacopter drone, autonomous fire suppression, fire detection, emergency response

1. Introduction

Fire incidents in dense urban areas present significant challenges due to issues such as high population density, traffic congestion, and limited access to fire-prone locations. These challenges are compounded in cities like Dhaka, Mumbai, and Lahore, where the infrastructure often restricts the movement of conventional firefighting vehicles. As urbanization continues to accelerate globally, the need for innovative firefighting solutions has become increasingly urgent.

Blazeguard is a fantastic approach to overcome these challenges. Designed as a hexacopter drone, Blazeguard enhances firefighting capabilities by providing quick response and precise deployment of fire-extinguishing ball. This paper explores the design and development of Blazeguard, emphasizing its potential to revolutionize firefighting era. The drone's cutting-edge capabilities include autonomous fire detection, and targeted fire suppression, all of which contribute to mitigating the impact of fire accidents in challenging urban environments.

2. Methodology

2.1 Design and Structure

Blazeguard's design shown in Fig 1 is centered around stability, maneuverability, and precision. The hexacopter configuration offers superior flight stability and redundancy, crucial for maintaining control in the presence of environmental disturbances such as wind and smoke.

Mechanical Claws and Precision Dropping Mechanism: The drone features three custom-designed mechanical claws shown in Fig 2 capable of holding and deploying spherical fire-extinguishing ball. These claws

are actuated by MG995 servo motors, which are controlled wirelessly via a Bluetooth connection to a mobile application. The app, developed using MIT App Inventor and integrated with Arduino Uno, allows operators to control the drone's actions in real time.

Figures:

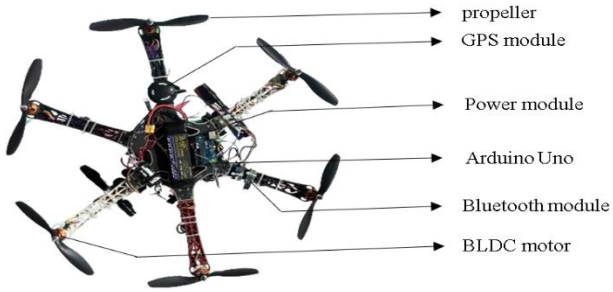


Fig 1: Top view of Blazeguard, showing the hexacopter layout.

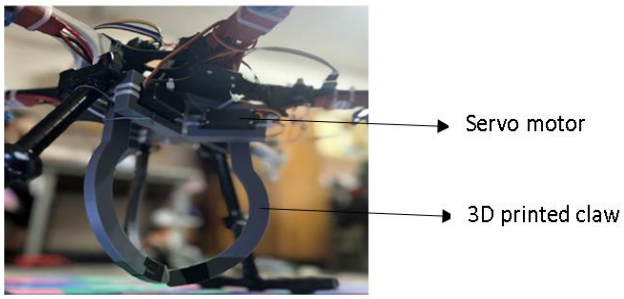


Fig 2: Close-up of the claw mechanism.

2.2 Hardware Components

The Blazeguard system is constructed using a combination of commercially available components and custom-fabricated parts to ensure reliability and performance:

- **Flight Controller**: APM 2.8 provides real-time control over the drone's flight dynamics, ensuring stability and responsiveness.
- **Transmitter and Receiver**: FS i6 transmitter paired with a compatible receiver, facilitating long-range communication between the operator and the drone.
- **Power Supply**: A 4500mAh LiPo battery shown in Fig 1, chosen for its balance of weight, capacity, and power output, supporting extended flight times.
- **Motors and Propellers**: High-efficiency 1400 kV brushless DC (BLDC) motors shown in Fig 1 paired with 8-inch propellers, providing the necessary thrust and maneuverability.
- **Microcontroller and Bluetooth Module**: Arduino Uno microcontroller coupled with an HC05 Bluetooth module to manage the servo motors and facilitate wireless communication with the control app which are shown in Fig 1.
- **GPS Module**: Ublox NEO-M8N GPS shown in Fig 1 for precise positioning and autonomous navigation, critical for accurate targeting of fire hotspots.
- **3D-Printed Claws**: The claws are made using PLA shown in Fig 3, providing a lightweight yet robust structure for holding and releasing fire-extinguishing balls.
- **IR Sensor**: This sensor helped us detecting infrared radiation emitted by fire, enabling the system to accurately locate fire sources even in low-visibility conditions.
- **Raspberry Pi:** The Raspberry Pi served as the central processing unit for fire detection and control.



Fig 3: SW model of the 3D-printed claws.

- **Mobile Application**: A user-friendly mobile application developed using MIT App Inventor enables real-time control of the drone's claw mechanism.

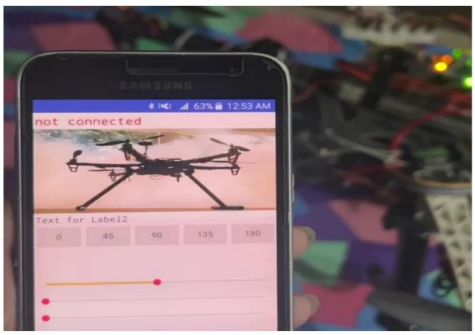


Fig 4: User interface of the mobile app for controlling the claw system.

2.3 Fire Detection and Response

2.3.1. Fire Detection and Localization

An infrared (IR) sensor mounted on the hexacopter, specifically calibrated to detect heat source indicative of fire. When the IR sensor detects a heat anomaly, it sends a signal to the onboard Raspberry Pi microcontroller. Upon receiving the heat signal, the Raspberry Pi initiates a GPS localization process using the GPS module to acquire the coordinates of the detected fire source. This information is then sent to the flight controller which manages the drone's autonomous flight path. The flight controller uses MAVLink communication protocol to interpret and execute GPS-based waypoints, enabling precise navigation toward the identified fire location.

2.3.2 Flight Control and Navigation

The flight controller interprets real-time GPS data from the Raspberry Pi and autonomously guides the drone to hover directly over the fire source. The FS i6 transmitter is used as an auxiliary control mechanism, allowing manual override if necessary.

2.3.3 Fire Extinguishing Deployment Mechanism

The deployment mechanism comprises MG995 servo motors controlled via Arduino Uno microcontroller, which receives wireless signals through an HC-05 Bluetooth module from user. The claws are configured to securely hold the extinguishing ball during flight and release it upon reaching the fire location.

3. Results

Blazeguard was subjected to a series of controlled experiments to evaluate its performance under realistic conditions. The following metrics were assessed:

- **Payload Capacity**: The drone successfully carried a payload of up to 1.1 kg when tested for 500g to 1500g payloads under normal environmental conditions. The loads for which the stability of drone was hampered are termed as unsafe here. This capacity is suitable for tackling small to medium-sized fire sources using fire-extinguishing balls available at local market.

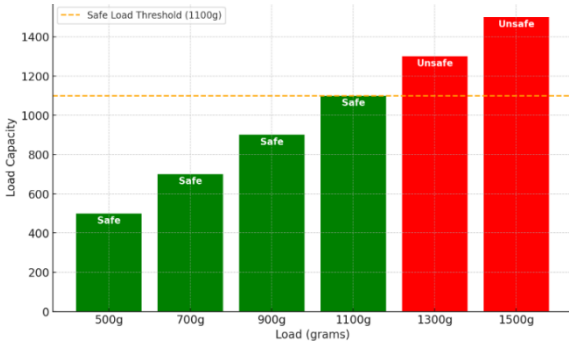


Fig 5: Bar chart showing the payload capacity.

Fire Detection Accuracy: We arranged a fire source at a specified location and tested the ability of the drone's detection system several times, which is shown in the below table.

Table 1. Table for accuracy of navigating the fire source locations.

Observation no.	Original location	Detected longitude	Detected latitude	Conformance to original location
1	23.725916355217116, 90.39480685413527	90.394807	23.725916	yes
2	23.725916355217116, 90.39480685413527	90.394807	23.725916	yes
3	23.725916355217116, 90.39480685413527	90.394338	23.726916	no
4	23.725916355217116, 90.39480685413527	90.394807	23.725916	yes
5	23.725916355217116, 90.39480685413527	90.394807	23.725815	no
6	23.725916355217116, 90.39480685413527	90.394807	23.725916	yes

4. Discussion

Blazeguard's successful deployment in experimental settings underscores its potential as a transformative tool in urban firefighting. Its ability to navigate confined urban spaces, combined with precise fire detection and suppression capabilities, makes it a viable alternative to traditional firefighting methods in certain scenarios.

The lightweight design and use of PLA material, while advantageous for payload capacity, present challenges regarding heat resistance. Future iterations of Blazeguard will focus on incorporating heat-resistant materials to enhance durability near fire sources. Additionally, expanding Blazeguard's autonomous capabilities through machine learning and advanced sensor integration will allow for more sophisticated decision-making and reduce the need for human intervention.

5. Future Prospects

The continued development of Blazeguard will focus on several key areas:

- **Heat-Resistant Materials**: Future designs will incorporate materials such as carbon fiber composites or flame-retardant coatings to enhance the drone's ability to withstand high temperatures.
- **Advanced Autonomous Navigation**: Implementing machine learning algorithms will enable Blazeguard to improve its fire detection accuracy, autonomously navigate complex environments, and optimize fire suppression strategies.
- **Swarm Robotics**: Adopting a swarm robotics approach will enable the coordination of multiple drones to cover large fire-affected areas efficiently. This approach will be particularly valuable in scenarios involving large-scale fires where coordinated efforts are necessary.
- **Enhanced Sensing Capabilities**: Integrating additional sensors for smoke detection, air quality monitoring, and thermal imaging will provide more comprehensive data, enhancing Blazeguard's situational awareness and decision-making capabilities.

6. Conclusion

Blazeguard represents a significant advancement in the field of firefighting, offering a rapid, precise, and effective response to fire incidents in urban environments. By integrating advanced fire detection, autonomous navigation, and precision-dropping mechanisms, Blazeguard addresses the limitations of traditional firefighting methods, especially in challenging urban settings. As urbanization continues to increase, innovative solutions like Blazeguard will play a critical role in protecting lives and property from fire hazards.

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